

Engineered Nanomaterials:

What are the Issues?

Rick Kelly, MS, CIH
Lawrence Berkeley National Laboratory



Prologue: My Career Has Been All About Particulate Matter!!



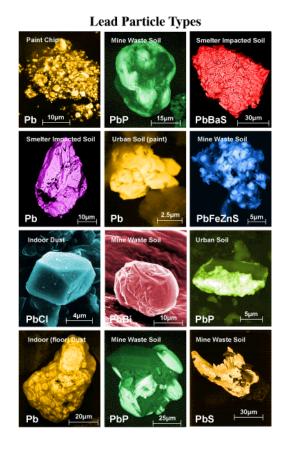


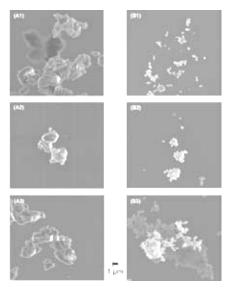
Asbestos



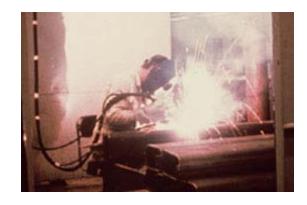
Silica

Lead





Beryllium



Welding Fume



EPA Nanotechnology White Paper

The Scale of Things - Nanometers and More

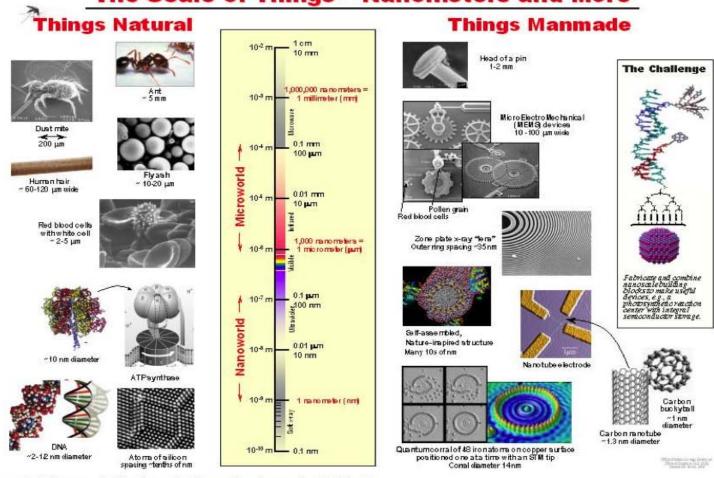


Figure 1. Diagram indicating relative scale of nanosized objects. (From NNI website, courtesy Office of Basic Energy Sciences, U.S. Department of Energy.)

6

What is Nanotechnology? What is a Nanoparticle?



- ASTM E 2456 perhaps most widely recognized definition of nanotechnology
 - —"<u>Nanotechnology</u>: A term referring to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nm. Such applications exploit the properties, distinct from bulk/macroscopic systems, of nanoscale components"
 - <u>Nanoparticle</u>: A sub-classification of ultrafine particle with lengths in 2 or 3 dimensions greater than 1 nm but smaller than about 100 nm and which may or may not exhibit size-related intensive property
 - People can reasonably be expected to be exposed by one or more route to these materials

Wide World of Nanotechnology





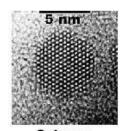
Nanoflowers



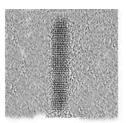
NanObamas



Nanodeposition and machining



Spheres



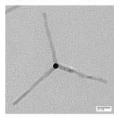
Rods



Wires



Ribbons

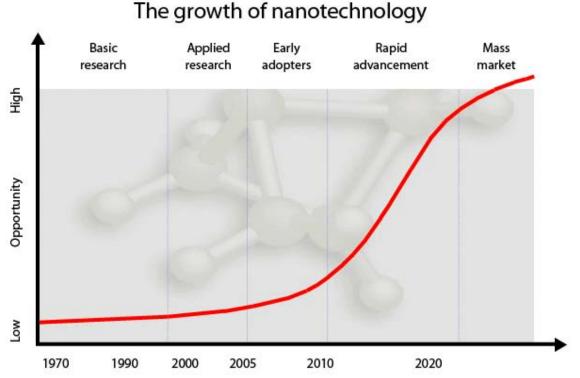


Tetrapods

What's the Big Deal?



 Nanoscale materials may possess properties that are novel and may be of tremendous value

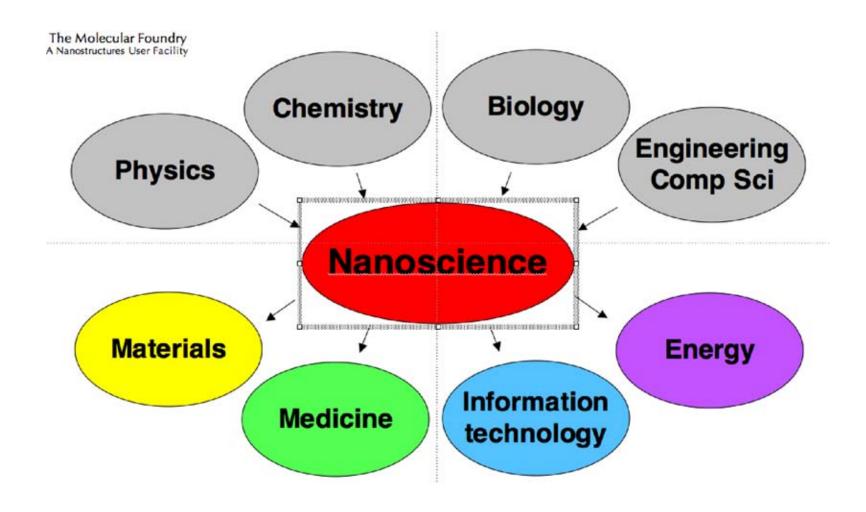


- Major advances in science, engineering, electronics and medicine
- •Opportunity to make lots of \$\$\$!



Nanotechnology Impacts Many Fields





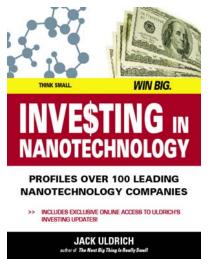
The Hype is On!













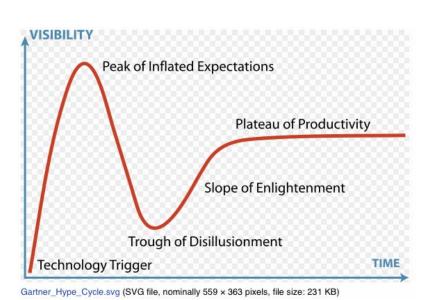


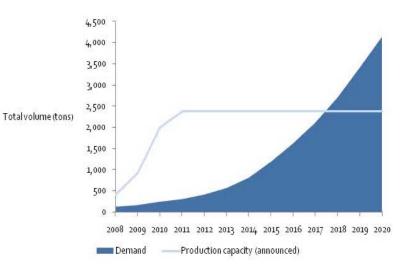
Surviving the Hype Cycle



Carbon Nanotubes

 Sporting goods, aerospace/defense, wind turbines automobile industry, batteries, electronics, filtration

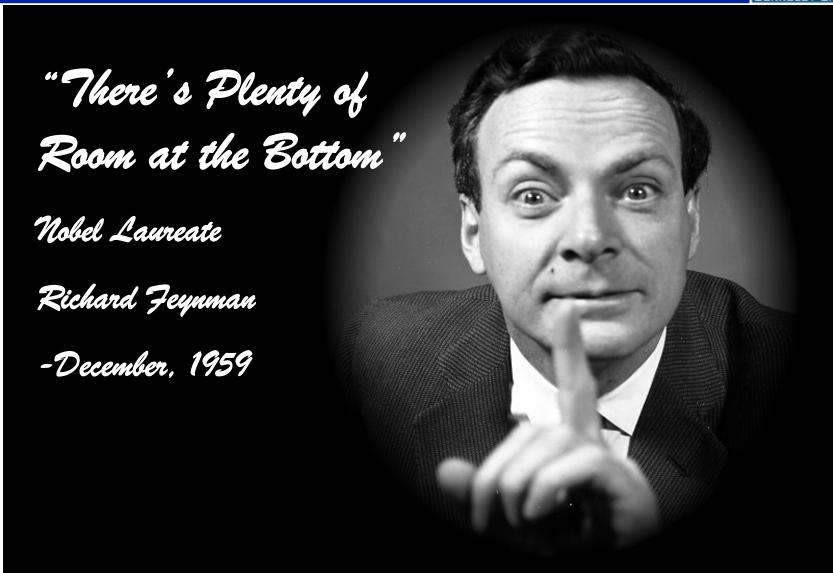




Wikipedia: Hype Cycle

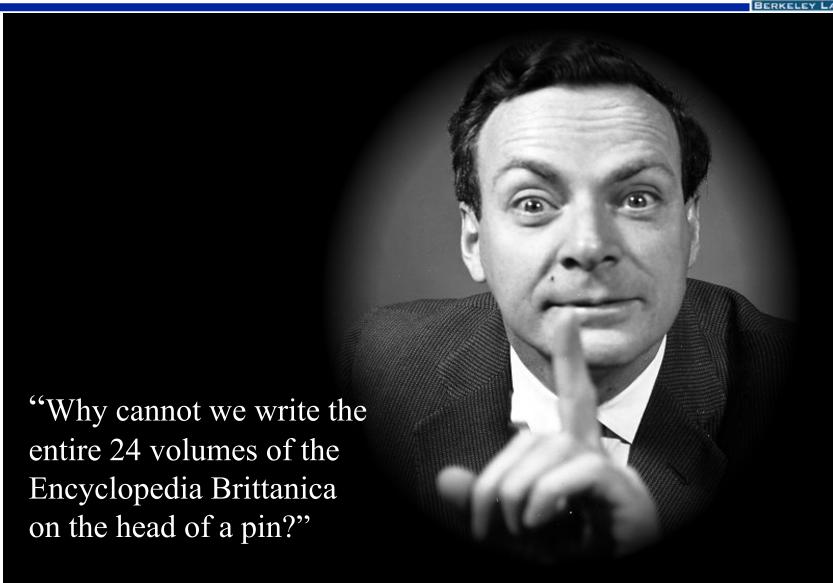
Where it all began (folklore review)





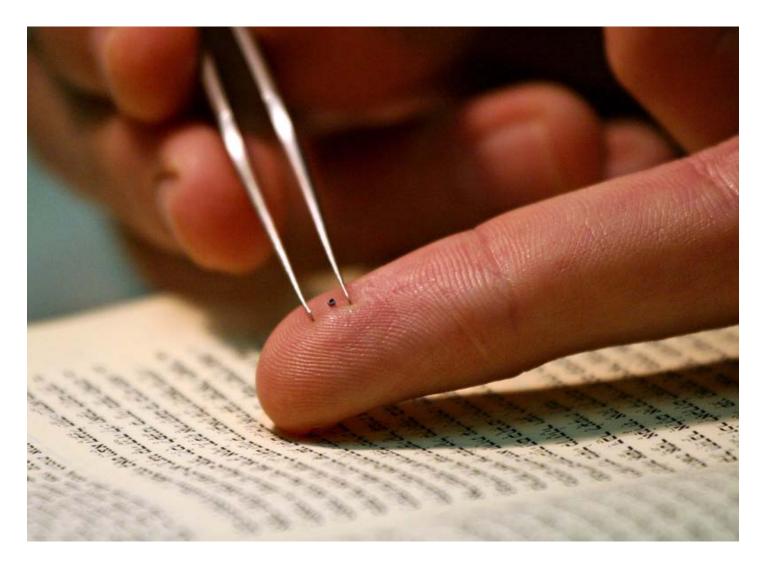
The Gauntlet





Bible on Head of a Pin, 2007

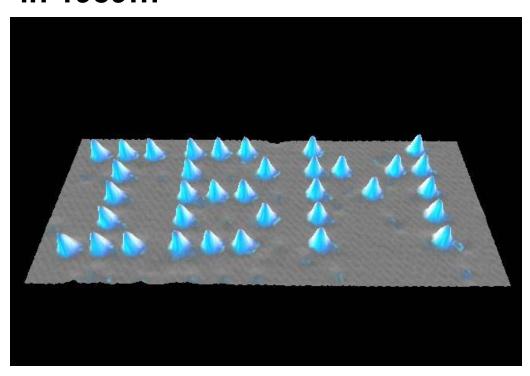




Iconic IBM Advertisement



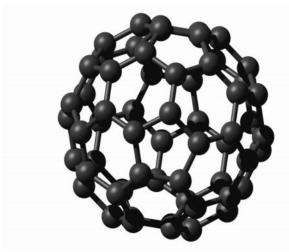
Feynman's dream comes to life in 1989...



• IBM scientists Don Eigler and Erhard Schweizer arrange 35 xenon atoms with an Scanning Tunneling Microscope to spell out the company name

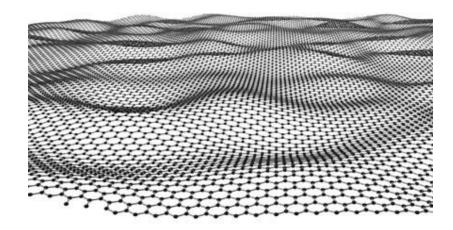
The Royal Swedish Academy of Science Takes Notice of Nanotechnology





•1996 Nobel Prize in Chemistry Awarded for discovery of the Bucky Ball

The State Molecule of Texas!

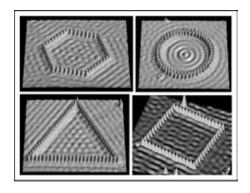


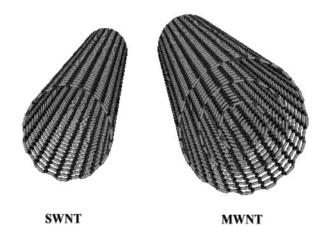
•2010 Nobel Prize for the discovery of Graphene

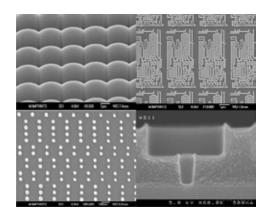
Two Approaches Bottom Up and Top Down Nanotechnology



Bottoms Up: Build one molecule or element at a time



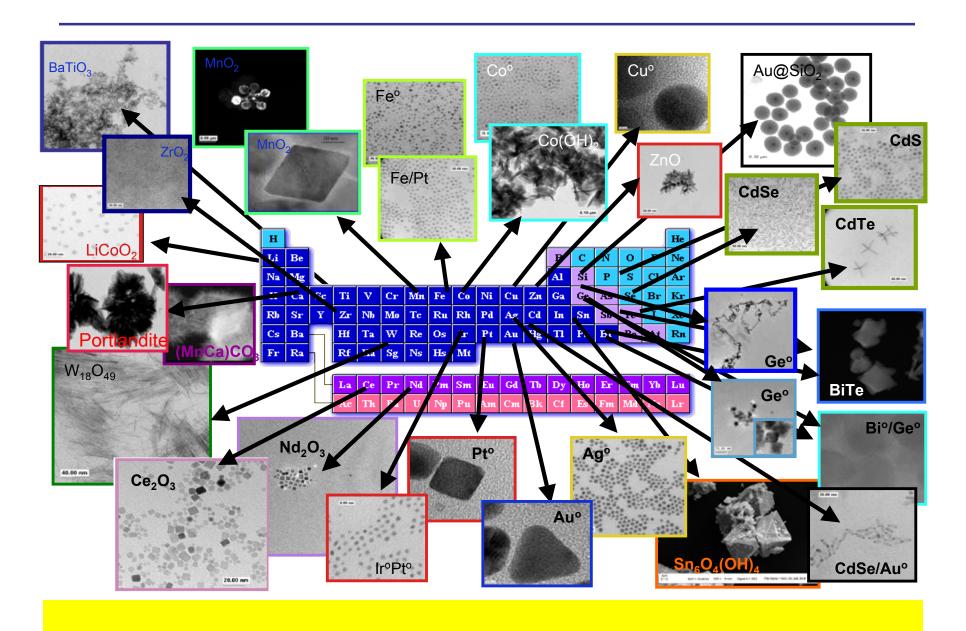






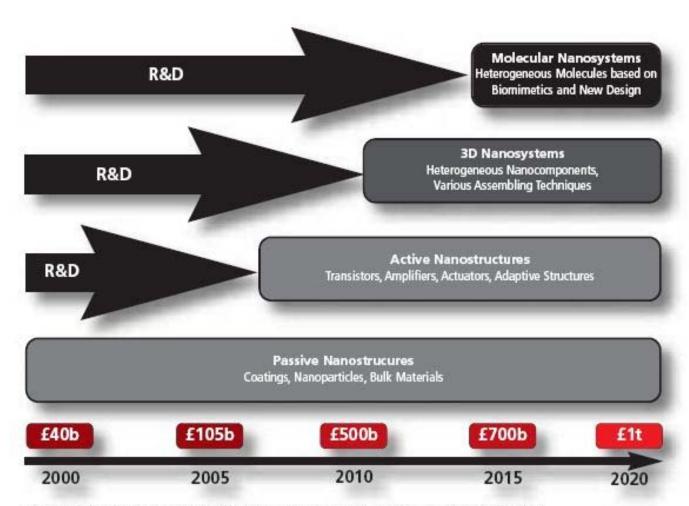
Top Down: Form out of larger piece of material

Wide variety of elemental compositions at the nanoscale



Proposed evolution of nanotechnology



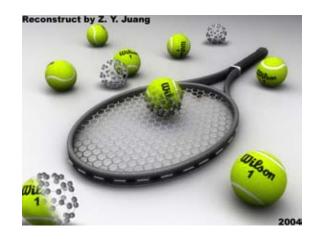


Market data based on estimates from Luxcapital - THE NANOTECH REPORT™ 2003, DTI - NEW DIMENSIONS FOR MANUFACTURING - A UK STRATEGY FOR NANOTECHNOLOGY 2002 & CMP Cientifica - THE TINY REVOLUTION 2002

We are all nano-consumers in 2010

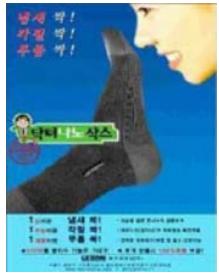










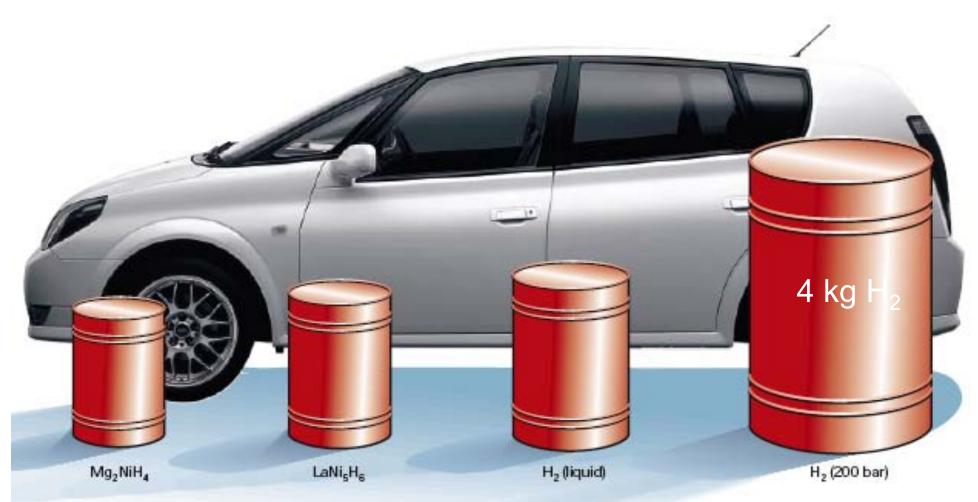






Materials for hydrogen storage

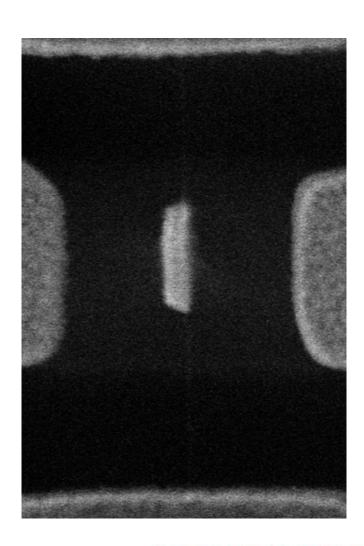


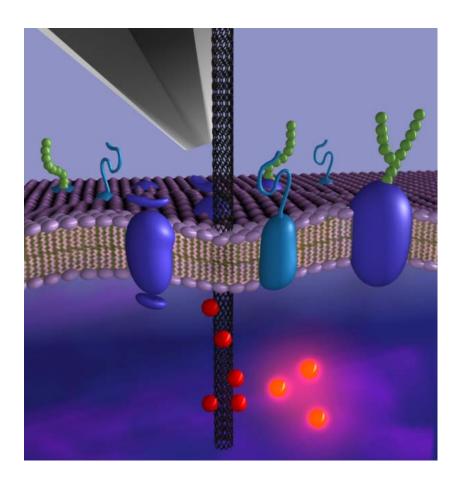


Hydrides, alloys, intermetallics, alanates, carbon nanostructures, (graphite,nanotubes), large surface area solids

More Sophisticated Applications

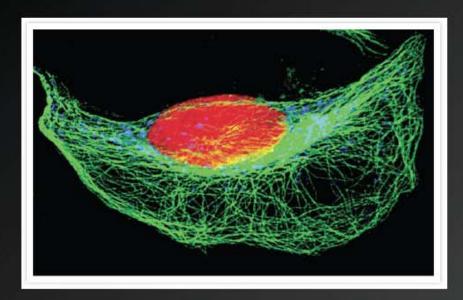




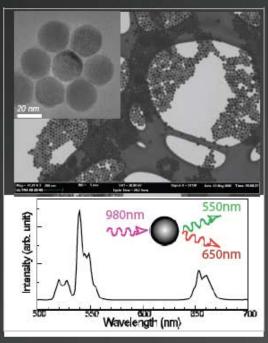




Biolabeling with quantum dots and upconverters



Multicolor cell imaging with quantum dots (Q-dot, Inc)





G. Han, S. Wu

So Why Are We Concerned?





- •Nanoparticulate material is being introduced to commerce before we have a full understanding of:
 - Toxicity
 - Exposure Potential
 - Medical surveillance
 - Exposure assessment
 - Protective Measures
 - Environmental Fate

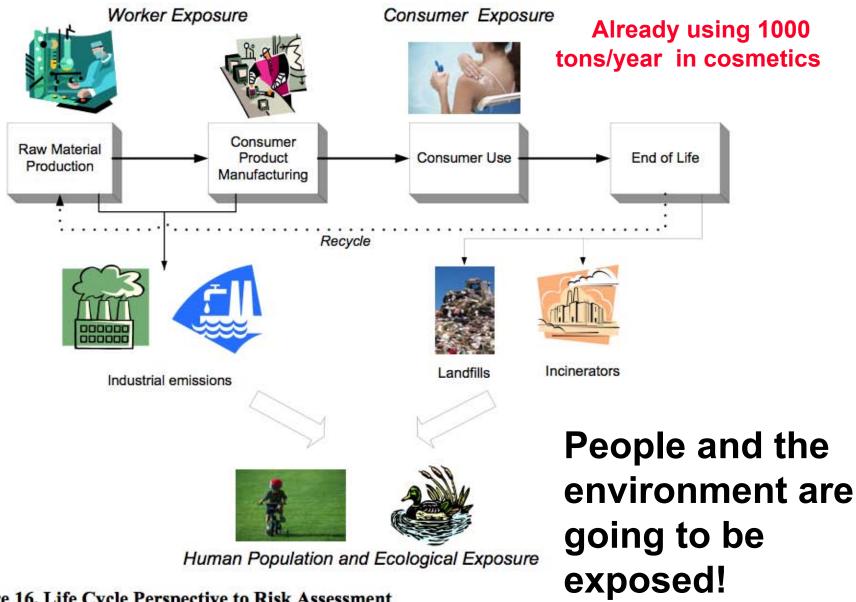


Figure 16. Life Cycle Perspective to Risk Assessment

We are all nano-consumers in 2010



 By 2010, nanomaterials are extensively incorporated into >600 consumer products

2008 Easton Stealth \$249.95 Comp Youth Baseball Bat CNT -11oz. LCN6 [LCN6]



2008 Easton Stealth Comp Youth Baseball Bat CNT -11oz. LCN6

Easton Stealth Comp Features:

 CNT Carbon Nanotube technology and Patented IMX[™] - Integrated MatriX technology strengthens composite structures, optimizing designs and materials for maximum performance







Carbon Nanotubes Are Here Already!









CNTs make sports equipment stronger, lighter, more profitable, cooler!

2008 Easton Stealth \$249.95 Comp Youth Baseball Bat CNT -11oz. LCN6 [LCN6]



2008 Easton Stealth Comp Youth Baseball Bat CNT -11oz. LCN6

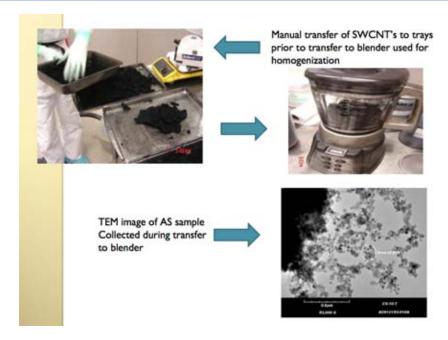
Easton Stealth Comp Features:

 CNT Carbon Nanotube technology and Patented IMX[™] - Integrated MatriX technology strengthens composite structures, optimizing designs and materials for maximum performance



People Are Being Exposed in Factories











Drinking Too Much Nano Silver?



•Man turned blue from drinking nano silver particles in a "health drink"



The New Silver Solution can't turn your skin blue, ever!

The New Silver Solution has had seven independent safety studies completed on their products, including: in-vivo (living) studies at up to 200 times the normal adult dosage; injected and ingested studies at levels of up to 5000 milligrams per kilograms of body weight, using not only the regular 10 ppm supplement, but also independent studies using the 32 ppm product. The New Silver Solution also has cellular studies showing that the product (even at extra-strength levels) is non toxic to human cells. All seven safety studies have shown that the New Silver Solution is completely non-toxic at the levels at which they are recommended for use.

Newer nanosilver "health" products claim to prevent the blues!

Gone Too Far!





What is Consumer Reaction?





Some People Are Showing their Concern!











Some People Seek to Avoid Nano



FIND YOUR SUNSCREEN

Г

Water-resistant/sweatproof

-Marketed for

children/babies

□Good UVA

protection

¬No

nano-particles

Web site helps you select nano free sunscreen!

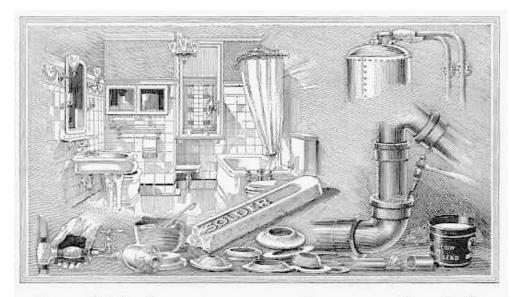


People Have Been Burned Before



Miracle materials

- -Asbestos
- —Lead
- —PCBs
- -MTBE
- -Nano?



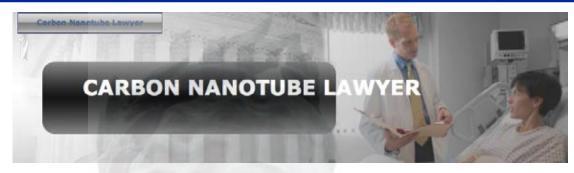
Lead helps to guard your health





The Lawyers Are Mobilizing!











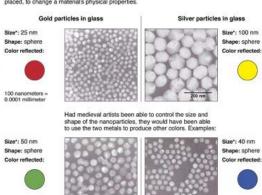
Nanotechnology Is Not All New





The First Nanotechnologists

Ancient stained-glass makers knew that by putting varying, tiny amounts of gold and silver in the glass, they could produce the red and yellow found in stained-glass windows. Similarly, today's scientists and engineers have found that it takes only small amounts of a nanoparticle, precisely placed, to change a material's physical properties.







Size*: 100 nm Shape: sphere





"Engineered"
 gold and silver
 nano particles of
 different sizes
 make different
 colored stained
 glass

Nanoparticles Have Been Produced Commercially for Decades



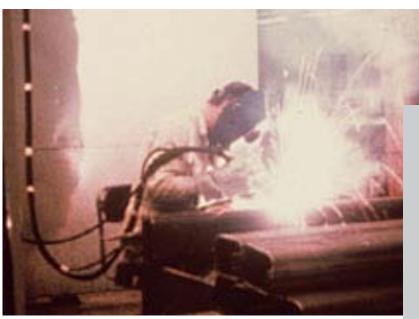
- Carbon black–100 years
- Fumed silica
- Iron oxide
- Titanium dioxide
- Aluminum oxide
- Zirconium oxide
- Nanoclays



Aeropulse Carbon Black Factory
From their web site

Nanoparticles Are Not All Engineered

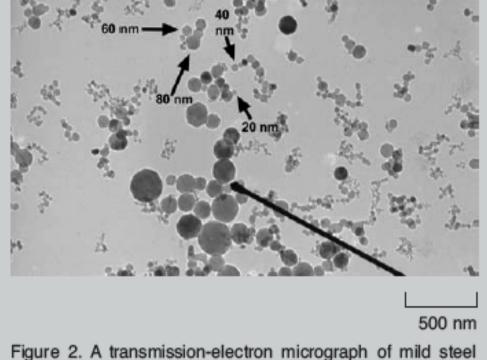




Welding fume

Oxides of zinc, iron, chromium, aluminum, or nickel mostly in the nanorange when fresh

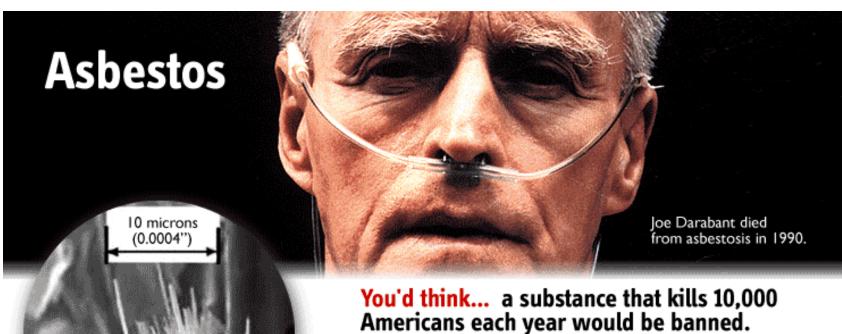
Picture - UC San Francisco



gas metal arc welding fume.

Your Fathers Natural, Hollow Nanotube





You'd think... that Congress would do everything possible to help those afflicted with asbestos diseases.

Think again.

Photograph of Joe Darabant Copyright Bill Ravanesi | About the photographer [click for next page]

Severe Nanoparticle Exposures!



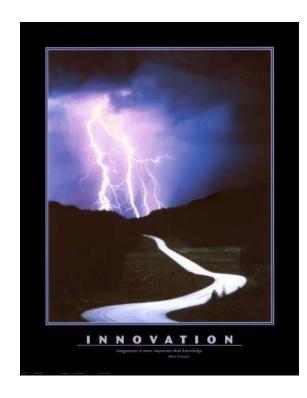
Smoke is largely composed of nanoparticles



But What Are the Risks?







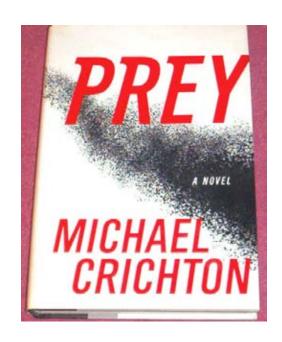


Michael Crichton 2002 Novel



 Tells of military nanobots run amuck!



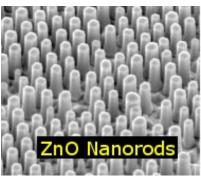




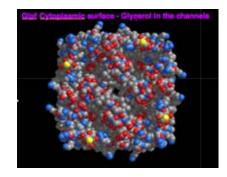
Primary EH&S Issue: Unbound Engineered Nanoparticles



Not firmly attached to a surface



 Not part of a bigger item (e.g., microchip, cell wall)



•Can result in exposure via inhalation, skin absorption or ingestion (or other nanospecific routes of exposure!)



Potential for Novel Toxicity



 Properties of nanoscale materials may be fundamentally different from bulk materials of same composition

Among the new properties of nanoscale materials

may be:

— Enhanced toxicity of materials
Toxic in bulk form

— New toxicological properties not seen in bulk material



From NIOSH

The Magic Nano Mess



- "Nanotechnology for absolute cleanliness"
- Dozens of people in Europe were sickened from inhaling this new anti-scum bathroom product
- Didn't really contain nanoparticles
- Illegal use of the TUV approval label--TUV sued them



Taiwan Multiple Fatality Report



- Seven young women (aged 18–47yrs) working in a paint factory and exposed to nanoparticles for 5–13months fell ill and were admitted to hospital.
- Two subsequently died.
- Pathological examinations of the patients' lung tissue showed nonspecific inflammation, fibrosis and foreignbody granulomas (tumours resulting from inflammation) of the pleura (membrane around the lungs).
- Transmission electron microscopy revealed nanoparticles of polyacrylate lodged in the cytoplasm and the nucleus of cells and in the chest fluid.
- The polyacrylate nanoparticles were confirmed in the workplace.

•Far from clear that the nanoparticles played a big role in this tragic event

Problem: Lack of Data



- Many nanoparticles seem to be more toxic than their micron scale counterparts
- Few nanoparticles have been studied adequately
- Short term or questionable tox tests
- Treating all nanoparticles as highly toxic is expensive and will certainly be overkill in many cases (but which cases?)

Yet these nanomaterials are being rapidly introduced into the market!

Analogy: Elixir of Sulfanilamide



- A 1937 oral preparation of an established antibiotic made by S. E. Massengill Company
- Solvent was toxic
- Promptly killed >100 people
- President of Massengill famously said: "There was no error in the manufacture of the product. We have been supplying a legitimate professional demand and not once could have foreseen the unlooked-for results. I do not feel that there was any responsibility on our part".
- Led to the establishment of the FDA as we know it



Are CNTs Just Graphite Toxicologically?



MATERIAL SAFETY DATA SHEET

Manufacturer:

Houston, TX 77084



Product:

Carbon Nanotubes

Section 1 Product Identification

Chemical Name: Carbon Fullerene

Formula: Carbon

Chemical Family: Synthetic Graphite

Synonyms: Carbon Nanotubes

CAS Number: 7782-42-5 (Graphite)

Section 2 Composition and Information on Ingredients

Component %
Synthetic graphite Up to 1

% Up to 100%

OSHA/PEL 15 mg/m³ (total dust) ACGIH/TLV 2 mg/m³ TWA

5 mg/m³ (respirable fraction)

Metallic impurity Balance

•2004 MSDS

- One of the early commercial manufacturers of CNTs
- Quoted OELs are for graphite, a relatively low toxicity material
- •Does this make sense?

Pulmonary Toxicity: <u>All</u> Published Instillation/Aspiration Studies up to Mid 2008

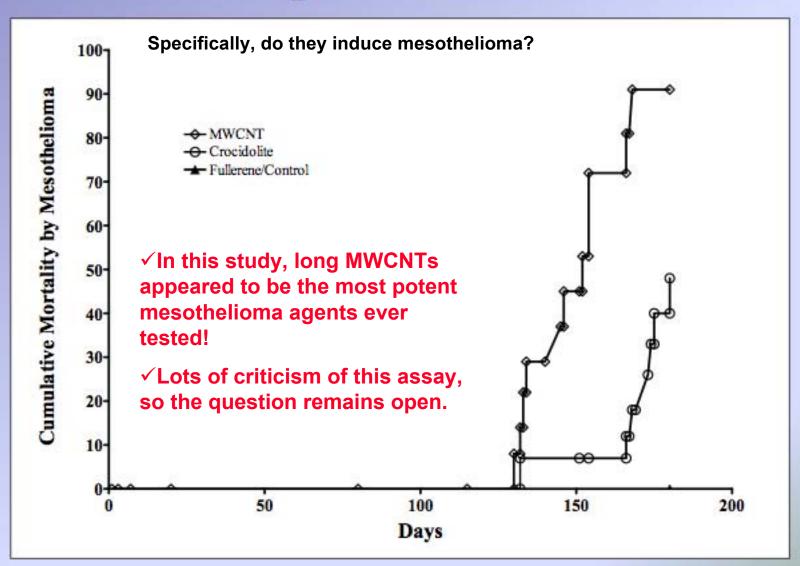


| Year | Author | Species | Granuloma | Inflamm | Diffuse |
|-------|-----------|---------------|------------|---------|----------|
| licai | Author | Opecies | Granaionia | minamin | |
| | | | | | Fibrosis |
| 2001 | Huczko | Guinea pig | _ | No | _ |
| 2004 | Warheit | Rat | Yesa | Yesb | No |
| 2004 | Lam | Rat | Yes | Yes | _ |
| 2005 | Muller | Rat | Yes | Yes | Yes |
| 2005 | Huczko | Guinea | Yes | Yes | Yes |
| | (Grubek- | pig | | . 00 | 100 |
| | Jaworska) | | | | |
| 2005 | Shvedova | Mouse | Yes | Yesb | Yesd |
| 2006 | Mangum | Rats | Yes | No | Yes |
| 2006 | Carrero | Mice | Yes | Yes | _ |
| | Sanchez | | | | |
| 2007 | Shevdova | Mice | Yes | Yes | Yes |
| 2008 | Han | Mice | _ | Yes | _ |

 Limitation: It was not clear that the adverse responses to instilled / aspirated CNTs would be the same if the CNTs were inhaled!

A = non-uniform, b = transient, c = by choking, d = progressive

Do MW-CNTs Behave Like Asbestos in p53+/- Mice?



2010 MSDS



ACGIH/TLV 2 mg/m³ TWA





MATERIAL SAFETY DATA SHEET

Manufacturer: Carbon Nanotubes Product:

Product Identification Section 1

Chemical Name: Fullerene Nanotube Formula: Carbon Chemical Family: Graphitic carbon Carbon Nanotubes Synonyms:

Section 2 Composition and Information on Ingredie

Component OSHA/PEL Synthetic graphite* 15 mg/m³ (total dust) Up to 100% 5 mg/m³ (respirable fraction)

Metallic impurity Balance

Disclaimer: provides the information contained herein in good faith and makes no representation as to its comprehensiveness or accuracy.

^{*} Exposure limits based on synthetic graphite

Safe Handling of Engineered Nanoparticles







Baytubes® Carbon Nanotubes Safe Handling Guidelines



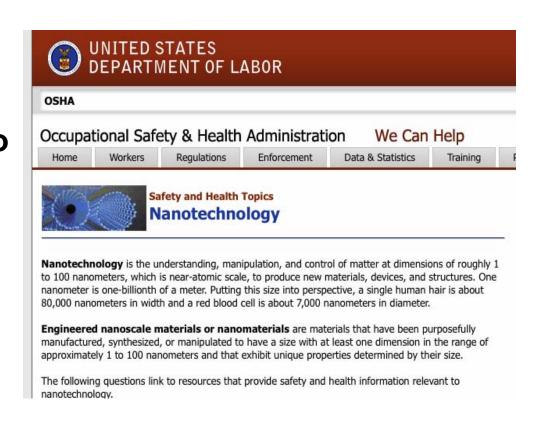
Regulation of Nanoparticles

OSHA/CaIOSHA EPA DTSC EU (REACH, RoHS)

OSHA Regulation of Nanoparticles



- Federal OSHA
 - Nothing <u>specific</u> to nanoparticles exists in Federal OSHA for.



OSHA Regulation of Nanoparticles





A variety of companies are researching and developing nanotechnology. Although there are nanomaterials in a few products used in the construction industry, most of these activities fall under OSHA General Industry standards. This page highlights some of the applicable General Industry OSHA standards.

Standards

Section 5(a)(1) of the Occupational Safety and Health Act of 1970 (29 U.S.C. 654), often referred to as the General Duty Clause, requires employers to "furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees." Section 5(a)(2) requires employers to "comply with occupational safety and health standards" promulgated under this Act.

Note: Twenty-four states, Puerto Rico and the Virgin Islands have <u>OSHA-approved State Plans</u> and have adopted their own standards and enforcement policies. For the most part, these States adopt standards that are identical to Federal OSHA. However, some States have adopted different standards applicable to this topic or may have different enforcement policies.

Applicable Standards

The following are examples of standards that may be applicable in situations where employees are exposed to nanomaterials.

- 1904, Recording and reporting occupational injuries and illness [Topic Page]
- 1910.132, Personal protective equipment, general requirements [Topic Page]
- 1910.133, Eve and face protection [Topic Page]
- 1910.134, Respiratory protection [Topic Page]
- 1910.138, Hand protection
- 1910.141, Sanitation
- 1910.1200, Hazard communication [Topic Page]
- 1910.1450, Occupational exposure to hazardous chemicals in laboratories [Topic Page]
- Certain substance-specific standards (e.g., 1910.1027, Cadmium) [Topic Page]

 Yet, a number of standards can be applicable to the handling and manufacture nanoparticles.

Cal/OSHA Regulation of Nanoparticles



Cal/OSHA

- —Not planning any regulation in near term unless they are forced to by petition or a law
- —Have investigated 2 northern California cases involving complaints by workers allegedly exposed to nanoparticles

EPA Has Many Possible Regulatory Roles WRT Nanoparticles



- Prohibit/Regulate introduction of nanoparticles into commerce under TSCA:
 - —Underway for CNTs and other nanoparticles since 2008
- Regulate as a pesticide (FIFRA):
 - —Underway for nano-silver
- Prohibit releases to air (Clean Air Act) or Water (Clean Water Act, Safe Drinking Water Act)
- Classify as hazardous Waste (RCRA)

EPA Officially Announces The Regulation of CNT Import and Manufacturing



Federal Register/Vol. 73, No. 212/Friday, October 31, 2008/Notices

TION CONTACT:

1/562-8887.

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10–30–08; 8:45 am]

ROTECTION

UND-2008-0792,

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[EPA-HQ-OPPT-2004-0122; FRL-8386-6]

Toxic Substances Control Act Inventory Status of Carbon Nanotubes

AGENCY: Environmental Protection

Agency (EPA). ACTION: Notice.

SUMMARY: This document gives notice of the Toxic Substances Control Act (TSCA) requirements potentially applicable to carbon nanotubes (CNTs). EPA generally considers CNTs to be chemical substances distinct from graphite or other allotropes of carbon listed on the TSCA Inventory. Many CNTs may therefore be new chemicals under TSCA section 5. Manufacturers or importers of CNTs not on the TSCA Inventory must submit a premanufacture notice (PMN) (or applicable exemption) under TSCA section 5 where required under 40 CFR part 720 or part 723. In order to determine the TSCA Inventory status of a CNT, a manufacturer may submit to EPA a bona fide intent to manufacture or import under 40 CFR 720.25.

processing, or usin commercial purpos

T' isting is no

affective by this act entities not listed in the affected. The Note Industrial Classific (NAICS) codes have assist you and other whether this action certain entities. If y questions regarding this action to a particle technical personal personal

B. How Can I Get C Document and Otl: Information?

1. Docket. EPA h docket for this actiidentification (ID): OPPT-2004-0122. docket are listed in available at http://a Although listed in information is not e.g., Confidential H

- Manufacture and import of carbon nanotubes must be approved by the EPA.
- Importers and manufacturers must submit PMN to EPA, conduct a tox study and sign a consent decree before they can sell CNTs.
- Consent decree strongly limits what company can do with the CNTs and requires use of employee protection
- Use limits and safety controls apply to anyone buying that CNT product!

Example: Thomas Swan MWCNT Consent Decree



- Personal Protective Equipment Details
 - Applies to all activities where exposure may occur, including cleaning, storage, maintenance of equipment (other than exempt lab work)
 - —Requires demonstration through testing of the impermeability of the gloves and body clothing used for protection
 - —Requires a respirator with protection factor of 50 or above and N100 filters
 - —Contractually applies to everyone who uses Thomas Swan CNTs!

EPA Issues Significant New Use Rules (SNURs) for Multi-Walled Carbon Nanotubes



- After signing a Section 5(e) Consent Order, EPA generally promulgates a Significant New Use Rule (SNUR) that mimics the Consent Order to bind all other manufacturers and processors to the terms and conditions contained in the Consent Order for that exact, specific PMN material.
- The SNUR requires that manufacturers, importers and processors of PMN substances notify EPA via a SNUN at least 90 days before beginning any activity that EPA has designated as a "significant new use". These new use designations are typically those activities prohibited by the Section 5(e) Consent Order."

General Research Exemption to SNURs



- SNUN Exception for Research: 40 CFR 721.47:
 - —Small quantity, only for R&D
 - —Standard lab procedures
 - —Only handled by "technically qualified individuals"
 - —Additional rules apply to R&D that exceeds the scope of "laboratory scale"



REACH: EUs Answer to TSCA

CNTs Must Be Registered in the EU (REACH)



Registration of Carbon Nanoscale Materials Required Under REACH

POSTED ON OCTOBER 29, 2008 BY JOHN C. MONICA, JR.

The EC's 2006 Registration, Evaluation, Authorisation and Registration of Chemicals ("REACH") regulations place "the responsibility for the management of the risks of [chemical] substances with. . .[the companies that] manufacture, import, place on the market or use [the] substances in the context of their professional activities." Guidance on Registration, Guidance for the Implementation of REACH, European Chemicals Agency, Version 1.3, May 2008, at p. 12.

To this end, REACH requires companies manufacturing or importing chemical substances in quantities greater than one ton per year to register those substances before they "can be manufactured, imported or placed on the market." As part of these requirements, "manufacturers and importers need to collect or generate data on the substances and assess how risks to human health and environment can be controlled by applying suitable risk management measures." This can often be an expensive and time consuming process.

Providing some relief in certain circumstances, Article 2(7)(a) of Regulation (EC) No 1907/2006 provides that certain substances are exempt from registration under REACH because "sufficient information is known about these substances that they are considered to cause minimum risk because of their intrinsic properties." These substances are listed in REACH Annex IV.

On October 8, 2008, the EC removed carbon and graphite from Annex IV "due to the fact that the concerned Einecs and/or CAS numbers are **used to identify forms of carbon or graphite at the nano-scale, which do not meet the criteria for inclusion in" Annex IV**. We first posted on this possibility last June.



RoHS: Restriction of Hazardous Materials in Electronics

Restriction of Hazardous Substances (RoHS) in Electrical and Electronic Equipment



- EU rule (partially adopted in CA) that bans the use of toxic materials in some electronics
 - —Lead
 - -Mercury
 - —Cadmiun
 - —Chrome 6+
 - —Polybrominated biphenyls
 - —Polybrominated biphenyl ether

MWCNT Are Proposed to Be Banned In Electronic Equipment in the EU



EP Committee Adds Nanosilver and Long Multi-Walled Carbon Nanotubes to Proposed RoHS Recast

Posted on June 8, 2010 by Lynn L. Bergeson

On June 2, 2010, the European Parliament (EP) Committee on the Environment, Public Health, and Food Safety approved the proposed recast of the Directive on the Restrictions of Hazardous Substances (RoHS) in Electrical and Electronic Equipment, with 55 votes in favor, one against, and two abstentions. The Committee adopted amendments adding nanosilver and long multi-walled carbon nanotubes (MWCNT) to Annex IV, despite the fact that

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nanomaterials were not included in earlier proposals. In effect, there would be no threshold, with equipment prohibited from the market if it contained either nanosilver or long MWCNTs at "detectable levels." The Committee also adopted amendments that require equipment containing nanomaterials to be labeled, and for manufacturers to be required to provide safety data on the nanomaterials to the European Commission (EC). The Committee voted in favor of an "open scope," meaning that the RoHS Directive would apply to all electrical equipment, unless specifically excluded. The EP plenary vote on the amended proposal is scheduled for July 2010.

[•]http://nanotech.lawbc.com/2010/06/articles/international/ep-committee-adds-nanosilver-and-long-multiwalled-carbon-nanotubes-to-proposed-rohs-recast/

In UK, CNTs are Classified as Hazardous Waste





Health and Safety
Executive

Risk management of carbon nanotubes

Waste

The Environment Agency advises that this type of waste carbon nanotube material should be classified and coded as hazardous waste. Based on current information, they consider high temperature incineration at a hazardous waste incinerator as the preferred disposal method. Other technologies may be suitable if you can demonstrate that they render the wastes safe. CNT waste should be double-wrapped in sealed polythene bags. Pyrolysis above 500°C will oxidise CNTs completely. The disposal facility should provide adequate documentation of the disposal conditions and incineration temperature.

California DTSC Call In-Preliminary to Regulation







Linda S. Adams Secretary for Environmental Protection

Department of Toxic Substances Control

Maziar Movassaghi
Acting Director
1001 "I" Street
P.O. Box 806
Sacramento, California 95812-0806



Arnold Schwarzenegger Governor

February 16, 2010

CERTIFIED MAIL: XXXX XXXX XXXX XXXX

<<Contact_First_Name>> <<Contact_Last_Name>>

<<Company Name>>

<<Address1>>

<<Address2>>

Dear Mr/Ms/Dr (CONTACT NAME) or Sir/Madam:

On January 22, 2009, the Department of Toxic Substances Control (DTSC) sent letters to companies, universities and other entities producing or importing carbon nanotubes in California (copy attached). (company name) was one of those receiving a letter, which was sent under the authority of the California Health and Safety Code, Chapter 699, Sections 57018-57020. To date, we have not received a response to our letter from (company name).

Already Investigated CNTs



- What is the value chain for your company? For example, in what products are your carbon nanotubes used by others? In what quantities? Who are your major customers?
- What sampling, detection and measurement methods are you using to monitor (detect and measure) the presence of your chemical in the workplace and the environment? Provide a full description of all required sampling, detection, measurement and verification methodologies. Provide full QA/QC protocol.
- What is your knowledge about the current and projected presence of your chemical in the environment that results from manufacturing, distribution, use, and end-of-life disposal?
- What is your knowledge about the safety of your chemical in terms of occupational safety, public health and the environment?
- What methods are you using to protect workers in the research, development and manufacturing environment?
- When released, does your material constitute a hazardous waste under California Health &Safety Code provisions? Are discarded off-spec materials a hazardous waste? Once discarded are the carbon nanotubes you produce a hazardous waste? What are your waste handling practices for carbon nanotubes?
 - ✓ EPA/DTSC public meeting to discuss these findings Sept 22 in SF!

Next Nanoparticles of Interest



- Carbon nanotubes
- Cerium oxide
- Quantum dots
- Silver metal
- Titanium dioxide
- Zinc oxide

Of interest primarily based on rapid assimilation into industry and/or large scale of use or predicted use

End of Part 1



